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Ex Post Liability for Harm vs. *Ex Ante* Safety Regulation: Substitutes or Complements?

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We have benefitted from comments by Robert Cooter, Robert Gritz, Judy Lachman, Steven Shavell, V. Kerry Smith and participants in workshops at MIT, Colby and the Universities of British Columbia, Illinois and Washington.

Abstract

This paper concerns regulations of hazardous economic activities. Economists have generally viewed *ex ante* regulations (safety standards, Pigouvian fees) that regulate an activity before an accident occurs as substitutes for *ex post* policies (eg., exposure to test liability) for correcting externalities.

This paper shows that under uncertainty there are inefficiencies associated with the use of negligence liability. We also show that an *ex ante* safety standard can correct the inefficiencies associated with liability. In such a case, where both *ex ante* and *ex post* policies are used, it is efficient to set the safety standard below the level of precaution that would be called for if the standard were used alone.

I. INTRODUCTION

One of the main issues that dominates the economic literature on optimal regulation is the choice of the most efficient policy for correcting an externality. From its beginnings the literature has focused on alternative forms of what may be called _ex ante_ policies (e.g., safety standards, Pigouvian taxes, and transferable discharge permits) that affect an activity before the externality is generated. But in the past decade researchers have analyzed the ability of what may be called _ex post_ policies (e.g., exposure to tort liability) to control externalities.[1] These latter policies regulate the externality only after it has been generated and harm has occurred. The threat of suit causes the potential injurer to internalize the expected social damages and thus to take optimal precaution.

Economists have generally viewed _ex ante_ and _ex post_ policies as substitutes for correcting externalities. The usual policy recommendation has been to choose the less costly regulatory policy to administer. For instance, in the commonly cited case of chopping down a tree in one's yard, it is less costly to use threat of suit to force appropriate caution than to construct a myriad of permits and regulations covering tree-felling. An example at the other extreme is air pollution where it is less costly to promulgate well thought out regulations than to let each potential injured party take injurers to court. Rarely is the joint use of _ex ante_ and _ex post_ policies recommended for a given externality.[2]

This conclusion, however, stands in stark contrast to actual policy. One of the most noticeable features of current policy dealing with externality-generating activities in a wide number of areas is that ex ante and ex post policies are very frequently used jointly. Consider the following examples. The potential inefficiencies of incompatible neighboring property uses--e.g., a hospital located next to a noisy, dusty cement-manufacturing plant--are minimized by zoning ordinances (a form of ex ante regulation) and by simultaneously exposing the externality-generator to nuisance liability (a form of ex post regulation).[3] Similarly, society attempts to minimize the harms that new pharmaceuticals may inflict on users by requiring the manufacturers of drugs to engage in specific tests before the drugs are licensed by the federal Food and Drug Administration for prescription and sale (a form of ex ante regulation) and also by thereafter exposing the drug manufacturers to strict products liability (ex post regulation). In the field of environmental externalities, the potential harms of toxic wastes are regulated at the federal level by the Resource Conservation and Recovery Act (1982), which imposes ex ante siting and technological regulations on the generation and disposal of hazardous wastes, and the Comprehensive Environmental Resource, Compensation, and Liability Act (1979), which establishes ex post liability rules for the recovery of compensatory and punitive damages for harms imposed by hazardous wastes.

This phenomenon of complementary use of ex ante and ex post regulatory policies is so widespread that the dearth of persuasive theoretical arguments for this joint use is glaring. Various authors have identified inefficiencies associated with one or the other regulatory policy. In the case of ex ante regulation, the typical criticism is that the central regulator has imperfect information on accident costs and damages (Weitzman, 1974; Baumol and Oates, 1971; Rose-Ackerman, 1973; Shavell, 1984b), which leads to inefficient under-control of some wrongdoers and overcontrol of others. The typical criticisms of tort liability have been that suit may not always be brought against injurers, that bankruptcy provides an incentive for underprotection, and that uncertainty regarding the legal standard leads to over- or under-protection, depending on the circumstances (Brown, 1973; Cooter _et al_, 1979; Craswell and Calfee, 1986; Shavell, 1984b; Wittman, 1977). Shavell (1984b) appears to be alone in suggesting that _ex ante_ and _ex post_ regulation can complement one another in that their joint use can be preferred to using either alone to correct an externality.

This paper builds on two strands of the literature. We first identify a set of inefficiencies associated with _ex post_ liability. These inefficiencies are due to a potential injurer's being uncertain about whether or not a court will hold him liable in the event of an accident and suit. Our discussion formalizes and extends the results and conjectures of Craswell and Calfee (1985) and Calfee and Craswell (1984). In contrast to Shavell (1984b), we do not base our analysis upon the inefficiencies due to bankruptcy and uncertainty of suit. Having identified inefficiencies associated with tort liability, we then demonstrate how _ex ante_ regulation, if used jointly with tort liability, can correct some of those inefficiencies.

One of our strongest conclusions, and a startling one, is that when _ex ante_ and _ex post_ policies should be used jointly, efficiency generally requires that the _ex ante_ regulatory standard be set at a level that, if regulation were used alone, would provide a socially _suboptimal_ level of safety or precaution. Put somewhat differently to emphasize this unconventional conclusion, when tort liability rules are in place, it is _inefficient_ to set _ex ante_ regulatory standards at the socially optimal level where marginal costs of precaution equal the marginal benefits. The only instances when the _ex ante_ regulatory standard should be set at the social optimum are when there is no _ex post_ liability or, equivalently, when there is a zero probability of a judgment under _ex post_ liability. A final, concluding section elaborates on the policy implications of the model and suggests some extensions of the analysis for future research.

II. A MODEL OF NEGLIGENCE AND SAFETY REGULATION

Consider the case in which a risk-neutral firm (or any other economic agent) engages in a risky activity. As a result of that activity, accidents can occur. The firm can reduce the dangers associated with this activity by taking precaution. Precaution reduces expected accident costs but is costly to the firm.

Let x be the level of the firm's precaution in preventing an accident or reducing its severity. For simplicity, we will not consider the decisions of the potential victim by assuming she always takes the socially optimal level of precaution.[4] The injuring firm's costs of taking precaution are given by the function $C(x)$, which is upward sloping $[C'(x) > 0]$ and convex over the relevant region. An accident will occur with probability $p(x,\varepsilon)$ and will be of size (cost) $D(x,\varepsilon)$ where ε is a random variable representing the state-of-the-world and distributed with density function q_ε. Assume the expected value of ε is zero. Define $A(x)$ as the expected value of $p(x,\varepsilon)D(x,\varepsilon)$ over ε. Thus, $A(x)$ embodies both the accident size (D) and the probability of the accident occurring (p). The state-of-the-world is only revealed after a court has heard evidence after an accident has occurred. Assume $A(x)$ is convex and downward sloping over the relevant region $[A'(x) < 0]$. Assume that $[C(x) + A(x)]$ is strictly convex.

To avoid confusion, it is useful to preview the three fundamentally different levels of precaution we will consider. We first define the socially optimal amount of precaution, x^*, where the expected social costs of accidents are minimized. We then define the legal standard of care, $\bar{x}(\varepsilon)$, the court's interpretation of the social optimum, which is a function of ε since it is only revealed after an accident occurs. The third type of precaution is the firm's precaution level, $\tilde{x}$, chosen to minimize expected private costs to the firm. Our goal will be to compare $\tilde{x}$ and x^*.

The socially optimal amount of precaution for the potential injurer can be obtained by minimizing expected social costs, i.e.,

$$\min_x E\,[C(x) + p(x,\varepsilon)D(x,\varepsilon)] = \min_x [C(x) + A(x)]. \qquad (1)$$

At the unique level of x that minimizes Eqn. (1), x^*, the marginal cost of precaution equals the negative of the marginal expected cost of the accident, i.e.,

$$C'(x^*) = -A'(x^*), \qquad (2)$$

assuming the solution of Eqn. 1 is greater than zero.

The legal standard, as opposed to the social optimum, is an *ex post* parameter, revealed by the courts after an accident has occurred. Thus the legal standard is parameterized by the state-of-the-world: $\bar{x}(\varepsilon)$. In fact $\bar{x}(\varepsilon)$ is defined as the solution of

$$\min_{x}[C(x) + p(x,\varepsilon)D(x,\varepsilon)] \tag{3}$$

for which the first-order condition is

$$C'(x) + \frac{d[p(x,\varepsilon)D(x,\varepsilon)]}{dx} = 0, \tag{4}$$

assuming an interior maximum. Eqn. 4 implicitly defines $\bar{x}(\varepsilon)$. Since ε is a random variable, $x(\varepsilon)$ induces a distribution on x, which we term $q_{\bar{x}}$ or more simply, q. Clearly $E(x) = x^*$. Although in our model uncertainty in $\bar{x}$ is induced by uncertainty in accident costs, other authors have posited other reasons for uncertainty in $\bar{x}$.[5] The important point is that $\bar{x}$ is not known with certainty by the firm. It is at this point that the notion of liability enters. Under a negligence rule, the injurer is found liable for all damages if, and only if, his level of precaution was less than the legal standard of precaution.[6] Mathematically, the injurer's total expected costs are given by

$$TC(x) = E\ [C(x) + L(x,\varepsilon)p(x,\varepsilon)D(x,\varepsilon)] \tag{5}$$

where $L(x,\varepsilon)$, the liability rule, is defined by

$$\text{Negligence:}\quad L(x,\varepsilon) = \begin{cases} 1 \text{ if } x < \bar{x}(\varepsilon) \\ 0 \text{ otherwise} \end{cases} \tag{6}$$

Let $\tilde{x}$ be the level of precaution that minimizes (5). Ideally, $\tilde{x}$ should equal x* in which case the liability rule is <u>ex ante</u> efficient.

A basic result of Brown (1973) is that when the legal standard is defined as in (4), and the firm knows that standard with certainty (ε fixed), then the negligence rule is efficient. This conclusion in the case of negligence is qualified by Calfee and Craswell (1984). Their argument hinges on <u>ex ante</u> uncertainty on the part of the firm, regarding the legal standard, $\bar{x}(\varepsilon)$. They point out that at the optimal level of care, the marginal costs of precaution just offset the marginal accident costs from precaution. But the injurer also sees a marginal savings in liability due to the unpredictability of the legal standard. Thus, the potential injurer may take precaution $\tilde{x} \neq E(x(\varepsilon)) = x^*$. Unfortunately, for the most part Calfee and Craswell are unable to prove their conjectures and must rely on cogent argument and numerical examples.[7] Furthermore, their argument that liability may have inefficiencies leaves the door open for correcting some of that inefficiency with simultaneous <u>ex ante</u> regulation.

Shavell (1984b) provides the only thorough treatment of correcting inefficiencies of tort liability by supplementing it with <u>ex ante</u> safety regulation. Instead of relying on uncertainty, Shavell argues that negligence is inefficient because $L(x) < 1$. And this, he suggests, is due to a) a positive probability that suit will never be brought against an injurer; and b) because assets of the injurer are less than potential accident costs (D). For symmetry, Shavell also suggests that <u>ex ante</u> regulation by itself is inefficient because D is not known with certainty to the regulator (but is known by the firm).

The results of these conditions are shown in Figure 1. For a given accident size, first best precaution will always exceed precaution induced by liability since there is a positive probability of never being sued, even if an accident occurs ($L(x) < 1$). Furthermore, the firm need not plan for accidents whose damage exceeds the assets of the firm. In contrast, pure ex ante regulation requires one level of care for all firms. This means that firms that cause small accidents are over-regulated and firms that cause large accidents are under-regulated. A mixed regulatory system results in firms that cause little damage being regulated by the ex ante regulation and firms that cause great damage being regulated by the threat of liability. Given the inefficiencies built into ex ante safety regulation and ex post liability for harm, it is easy to show that a hybrid does no worse and frequently does better than either approach alone. This result is strikingly similar to that of Roberts and Spence (1976). They argue, in an entirely different context, for a hybrid system of price and quantity controls to optimally control an externality. The analogy to our problem is that quantity controls are akin to ex ante regulations and price controls are similar to tort liability (in that liability induces the firm to minimize marginal damage and marginal precaution costs).

The difficulty with the Shavell analysis is that it hinges on $L(x)$ being strictly less than 1. If bankruptcy is not a possibility and suit is never brought, then $L(x) = 1$ and there are no inefficiencies associated with liability.

We take a different approach in this paper. Similar to Craswell and Calfee (1986) we suggest that it is uncertainty over the legal standard that leads to inefficiencies with negligence. In fact in the next section we prove all of their conjectures as well as others regarding the efficiency of negligence liability. In the subsequent section of the paper we introduce ex ante regulation as a means of correcting some of these inefficiencies.

III. THE INEFFICIENCY OF NEGLIGENCE

Our basic model of negligence was developed in the previous section. The legal standard of precaution, $\bar{x}(\varepsilon)$, is defined implicitly by (4). Should an accident occur, litigation will reveal the true state-of-the-world, ε. If a court finds that the firm's level of precaution was less than $\bar{x}(\varepsilon)$, then the firm will be liable for all accident costs; if greater than $\bar{x}(\varepsilon)$, no liability will apply.

The firm does not know the state-of-the-world, ε, when it chooses $\tilde{x}$. The firm must choose an $\tilde{x}$ based on an uncertain legal standard, $\bar{x}$. As discussed in the previous section, uncertainty in accident costs, embodied in the random variable ε, induces uncertainty in $\bar{x}$. As defined above, we let q(x) be the injurer's subjective probability distribution around the legal standard, the level of precaution that the firm must provide to avoid being held liable for accident costs. We assume that q(x) is a continuous probability density with support $(-\infty,\infty)$.[8] The probability that the injurer's level of precaution x will end up being below the legal standard of care applied in the case of an accident is thus given by

$$R(x) = \int_{x}^{\infty} q(x)dx. \tag{7}$$

That is, $R(x)$ is the probability when all is said and done, after the court has passed judgment, that the injurer will pay damages $E[p(x,\varepsilon)D(x,\varepsilon)] = A(x)$. We have already assumed that $C(x)$ and $A(x)$ are convex. We now make the slightly stronger assumption that $[C(x) + A(x)R(x)]$ is strictly convex.

The essence of our model is presented in Figure 2. The expected legal standard, which is defined to be the socially optimal level of precaution, is where the marginal precaution costs just equal the negative of the marginal expected accident costs, as indicated in Eqn. 2. With uncertainty, the injurer does not know $\bar{x}$ precisely. The injurer's uncertainty about the legal standard to which it will be held accountable is embodied in $q(x)$. If the injurer takes $\tilde{x}$ amount of precaution, then the probability it will be held liable is the area under the density function from $\tilde{x}$ to ∞, $R(\tilde{x})$, the cross-hatched area in the figure. This is the probability that should an accident occur, the firm will be found to be taking an inadequate amount of precaution.

The injurer's objective function (in the presence of liability) is defined by (5) except that $L(x)$ is replaced by $R(x)$:

$$TC(x) = E[C(x) + R(x)p(x,\varepsilon)D(x,\varepsilon)] = C(x) + A(x)R(x), \tag{8}$$

which the firm attempts to minimize. $TC(x)$ is strictly convex, by assumption, and thus has a unique minimum. Let $\tilde{x}$ be the level of precaution that minimizes Eqn. (8). The first-order condition for the minimization is

$$TC'(\tilde{x}) = C'(\tilde{x}) + A'(\tilde{x})R(\tilde{x}) - A(\tilde{x})q(\tilde{x}) = 0, \qquad (9)$$

provided $\tilde{x}$ is greater than zero. Eqn. 9 is basic to much of our analysis and thus deserves some interpretation. The first term on the right-hand side of Eqn. 9 is the marginal cost of providing a unit of precaution. The second and third terms sum to the expected marginal liability costs of a unit of precaution and consist of two effects. The first of these terms $[A'(\tilde{x})R(\tilde{x})]$ is the marginal (reduction in) accident cost times the probability of being held liable for the accident if the firm has taken precaution equal to $\tilde{x}$. This term, which might be called the "injury effect," is negative because $A'(\tilde{x})$ is negative and $R(\tilde{x})$ is always positive. The injury effect represents a savings to the injurer from the application of greater precaution because accident costs are reduced. But there is also a savings from providing slightly higher precaution in that the probability of being held liable is reduced. The monetary savings is the product of the change in the probability of liability and total expected accident costs. This savings is captured in the term $[-A(\tilde{x})q(\tilde{x})]$. This term, which might be called the "liability effect," is negative because both $A(\tilde{x})$ and $q(\tilde{x})$ are positive.[9] Thus, the marginal liability costs can be decomposed into an injury effect and a liability effect, both of which are decreasing in precaution.

The question that arises is whether the level of precaution, $\tilde{x}$, chosen by the firm to minimize its expected costs is greater than, less than, or equal to the socially optimal level of precaution, x^* which is equal to $E(x)$? An evaluation of the relationship between $\tilde{x}$

and x^* can be made by evaluating the sign of $TC'(x^*)$ in Eqn. 9. Since by assumption $\tilde{x}$ minimizes $TC(x)$ and $TC(x)$ is strictly convex, $TC'(x) < 0$ for $x < \tilde{x}$ and $TC'(x) > 0$ for $x > \tilde{x}$. Thus, if $TC'(x^*) < 0$, then $x^* < \tilde{x}$; and if $TC'(x^*) > 0$, then $x^* > \tilde{x}$. Substituting Eqn. 2 into the expression for $TC'(x)$ (in Eqn. 9), noting that from society's point of view there is no uncertainty, and rearranging the terms gives

$$TC'(x^*) = C'(x^*)[1 - R(x^*)] - A(x^*)q(x^*). \tag{10}$$

Since $C'(x) \geq 0$ by assumption and $R(x) \leq 1$, then $C'(x^*)[1 - R(x^*)]$ in Eqn. (10) is nonnegative. Also, since by definition $A(x)$ and $q(x)$ are greater than or equal to zero, the term $-A(x^*)q(x^*)$ is nonpositive. Therefore, the sign of Eqn. (10) is indeterminate and the relationship between $\tilde{x}$ and x^* cannot be discovered without knowing the magnitude of the various terms. Any further evaluation of Eqn. 10 will require further assumptions regarding the nature of the distribution $q(x)$ and the size of the marginal cost of precaution. First let us turn to assumptions about the nature of the distribution $q(x)$.

A. <u>The Effect of the level of uncertainty about the legal standard</u>

We are concerned here with uncertainty regarding $\bar{x}$; i.e., the variance of $\bar{x}$ distributed as $q(x)$. We consider two cases, one where there is a great deal of uncertainty with regard to the legal standard, and one where there is little uncertainty with regard to the standard. An example of the first case is the great uncertainty regarding the appropriate standard of care under a new technology, e.g., genetic engineering. The level of scientific knowledge regarding the potential for accidents and the extent of the damages may be low, and it may therefore be difficult to determine in the first instances of accidents what the socially optimal level of precaution is testing, production, warnings, and disposal, is for genetically engineered output. An example of the second case, where there is very little uncertainty about the appropriate legal standard, might be the case for a well-recognized harm where the costs and benefits of accident precaution are well known and legal precedent is well established, e.g., automobile accidents.

We are concerned with the effect of uncertainty in $q(x)$ on the sign of $TC'(x^*)$ in (10). Before analyzing (10) we must be somewhat more precise about what we mean by more or less uncertainty. The conventional notion is that of second-order stochastic dominance.[10] But just because one distribution dominates another in this sense does not assure us that the distribution function will be any different at x^*, which is critical in the present analysis. To facilitate our comparative statics analysis, we will introduce a particular type of mean-preserving spread on $q(x)$:

$$q_\alpha(x) = \alpha q[\alpha(x-x^*) + x^*], \tag{11}$$

where (by assumption) the legal standard is distributed as $q(x)$, defined over the nonnegative reals, with expected value x^*. It can readily be seen that $q_1(x) \equiv q(x)$. Furthermore, q_α is a well-behaved density function for all values of $\alpha > 0$, and random variables distributed according to q and q_α have the same mean. As α decreases, the spread of q_α increases, as shown in Figure 3 for a hypothetical distribution. As α increases the probability mass becomes concentrated at the mean.

As uncertainty becomes larger, i.e., as α becomes smaller, $q(x^*)$ becomes smaller, and $TC'(x^*)$ in Eqn. 10 eventually becomes positive. This implies that $\tilde{x}$ is less than x^*. As uncertainty becomes less, i.e., as α becomes larger, the probability mass becomes concentrated at x^* and $TC'(x^*)$ becomes negative. This implies that $\tilde{x}$ is greater than x^*. We can now state our first result regarding the effect of uncertainty on the use of negligence as a liability rule.[11]

PROPOSITION 1. Assume that to the firm, the legal standard is uncertain (distributed as $q(x)$) but has an expected value of x^*, with $q(x^*) > 0$. If uncertainty regarding the legal standard (in the sense of Eqn.9) is sufficiently large (small), then the injurer subject to a negligence rule will underprotect (overprotect).

<u>Proof</u>: To prove that with sufficiently large uncertainty a firm will underprotect, we need to show that there exists a more spread-out version of $q(x)$ such that $TC'(x^*)$ in Eqn. (10) becomes positive. Eqn. 10 can be rewritten using q_α from Eqn. (11) as

$$TC'(x^*)=C'(x^*)[1-R(x^*)]-A(x^*)q_\alpha(x^*)=C'(x^*)[1-R(x^*)]-A(x^*)\alpha q(x^*) \quad (12)$$

Obviously, there exists an $\alpha > 0$ such that Eqn. (12) is positive (since $C'(x^*) > 0$). Conversely, since $A(x^*) > 0$ [because $A'(x^*) < 0$

and $A(x^*) \geq 0]$ and $q(x^*) > 0$, there exists an $\alpha > 0$ such that Eqn. 12 is negative.

Thus, even though the injurer's expected value of the legal standard is equal to the social optimum, uncertainty is sufficient to result in over- or underprotection.[12]

B. <u>The effect of the marginal cost of precaution at the social optimum</u>

We now consider the effect of $C'(x)$ on over- or underprotection, holding $q(x)$ constant. In Eqn. 10, if marginal costs of protection are sufficiently large, then $TC'(x^*)$ can be driven positive. This implies that $\tilde{x} < x^*$--underprotection. By a similar argument it is clear that as $C'(x^*)$ goes to zero, then $TC'(x^*)$ becomes negative, implying that $\tilde{x} > x^*$--overprotection.

PROPOSITION 2. If $q(x^*) > 0$, then for a sufficiently small (large) marginal cost of precaution at the social optimum, x^*, then the injurer will employ too much (little) precaution to prevent an accident when faced with a negligence rule.

C. <u>The effect of biased perceptions of the legal standard</u>

In the previous section we focused on the effect of uncertainty with respect to the legal standard on over- or underprotection. By assumption, the mean of the distribution was the social optimum; what we examined was the effect of changing the variance or spread of the distribution. We now introduce a bias in the firm's perception of $\overline{x}(\varepsilon)$. We are now concerned less with the spread of the distribution than with the extent to which the firm views the distribution of $\overline{x}$ as biased to one side or the other of the social optimum. In particular we consider the case where the bulk of the probability mass is either to the left or right of x* ($E[\overline{x}(\varepsilon)] \lesseqgtr x^*$).[13] It is somewhat difficult to argue why the firm alone should be biased in its perception of x*. A possible explanation is evidentiary uncertainty where the firms believe juries will consistently over- or underestimate accident costs of precautionary costs (Cooter and Ulen, 1986).

Consider the family of distributions defined by

$$q_\beta(x) = \beta q(\beta x) \tag{13}$$

for $\beta > 0$. Obviously, $q_1(x) = q(x)$. Further, if the mean and variance of a random variable distributed as q are μ and σ^2, then the mean of a random variable distributed as q_β is given by $\mu_\beta = \mu/\beta$ and $\sigma_\beta^2 = \sigma^2/\beta^2$.[11] Thus, as illustrated in Figure 4, for $\beta < 1$, the distribution is biased to the right; and for $\beta > 1$, it is biased to the left. Note that for some β, $q_\beta(x^*)$ can be made arbitrarily small with R_β arbitrarily close to 0 or 1, depending on whether β is small or large.

The case where q_β is biased to the right might be the case of a work-related harm in which it is difficult to show causality, e.g., an increased incidence of lung disease as a result of a firm's negligence two decades earlier. Conversely, suppose the firm significantly underestimates the expected legal standard. Then $R(x^*) \approx 1$. This might be the case in emotionally charged accidents where juries may have sympathy for victims.

PROPOSITION 3. If the distribution $q(x)$ is sufficiently biased to the left (right) in the above sense, and $q(x^*) > 0$, then the injurer will underprotect (overprotect) against an accident when faced with a negligence rule.

<u>Proof</u>: To prove that if the distribution is sufficiently biased one gets over- or underprotection, we parameterize $q(x)$ as in Eqn. 12. Eqn. 8 then becomes

$$TC'(x^*) = C'(x^*)[1 - R_\beta(x^*)] - A(x^*)q_\beta(x^*)$$

$$= C'(x^*)[1 - R_\beta(x^*)] - A(*)\beta q(\beta x^*). \qquad (14)$$

Since $R(x) \to 0$ as $x \to \infty$, clearly $R_\beta(x^*) \equiv R(\beta x^*) \to 0$ as $\beta \to \infty$. By continuity of $q(x)$, this implies that $\beta q(\beta x^*) \to 0$ as $\beta \to \infty$. Thus there exists a sufficiently large β for which $TC'(x^*)$ in Eqn. (14) becomes positive, implying that $\tilde{x} < x^*$. Therefore, for uncertainty sufficiently biased to the left, injurers will underprotect under a negligence rule. Trivially, as $\beta \to 0$, then $TC'(x^*)$ becomes negative: if uncertainty is sufficiently biased to the right, injurers will overprotect.

Note that as the distribution in Eqn. (13) shifts to the left (right), the variance on the distribution decreases (increases). The results of Proposition 1 suggest that if some other shift preserved variance, then the results of Proposition 3 would still hold.

This proposition has a straightforward interpretation: if the firm perceives the expected legal standard of precaution to be sufficiently less than the social optimum, then the injurer will underprotect; an analogous interpretation would apply to overprotection. This is an intuitively reasonable result and is probably less significant than our finding in Proposition 1.

IV. NEGLIGENCE AND *EX ANTE* REGULATION

We come now to the important public policy issue of whether efficiency is better served by joint use of a negligence rule and *ex ante* regulation (rather than negligence alone). We proceed by introducing an *ex ante* safety regulation into the model just developed.

The safety regulation specifies a minimally acceptable level of precaution. There is no uncertainty with regard to the regulatory constraint; that is, the firm and the regulatory agency know the level of the constraint and that it is enforced with certainty. Let the safety regulation specify that precaution must be at least s. How does information about the safety regulation influence the firm's perception about the (uncertain) legal standard of care? The firm knows that the legal standard of precaution cannot be less than s. But the firm may also perceive the legal standard to be significantly greater than s. This seems most closely to approximate the prevailing relationship between *ex ante* and *ex post* regulation where they are jointly used. For example, no court today accepts compliance with a regulatory agency standard as a complete defense against a complaint of negligence.

We first examine the impact from introducing the safety regulation on the injurer's level of precaution. We represent the introduction of *ex ante* regulation by changing the injurer's distribution around the legal standard of precaution. With a safety regulation, s, the injurer will not consider precaution below s. In effect, the firm's probability distribution on the legal standard is truncated at s. By assumption, there is zero probability that the legal standard will be below s. There are a number of assumptions that could be made about the firm's new truncated subjective distribution on the legal standard, $\underline{q}(x)$. And the reader should note that our remaining results hinge on the relationship between q(x) and $\underline{q}(x)$. We make the simplest assumption, that $\underline{q}(x)$ has a conditional distribution

$$\underline{q}(x) = q(x \mid x \geq s). \tag{15}$$

Thus, we can write the conditional probability $\underline{R}(x)$ that the injurer will pay damages if its level of precaution is x as

$$\underline{R}(x) = \frac{R(x)}{R(s)}. \tag{16}$$

The objective function of the injurer who is subject to both a safety regulation and negligence liability becomes

$$\min_{x} \underline{TC}(x) = C(x) + A(x)\underline{R}(x) \tag{17}$$

Let $\hat{x}$ be the level of precaution that satisfies this minimization problem. Then $\hat{x}$ can be viewed as a function of s, $\hat{x}(s)$. For a given s, the first-order condition for $\hat{x}$ can be written as

$$\underline{TC}'(\hat{x}) = R(s)C'(\hat{x}) + A'(\hat{x})R(\hat{x}) - A(\hat{x})q(\hat{x}) = 0, \tag{18}$$

where $\hat{x}$ is understood to mean $\hat{x}(s)$.

The question that needs to be addressed is how the injurer's choice of $\hat{x}$ changes with a change of the _ex ante_ safety regulation s; i.e., what is the sign of $d\hat{x}/ds$? The answer to this question requires the total differentiation of the first-order conditions given in (18). The result of this total differentiation, upon rearrangement of terms, is

$$\frac{d\hat{x}}{ds} = \frac{q(s)C'(\hat{x})}{R(s)C''(\hat{x}) + A''(\hat{x})R(\hat{x}) - 2A'(\hat{x})q(\hat{x}) - A(\hat{x})q'(\hat{x})}. \tag{19}$$

By assumption, $C(x) + A(x)R(x)$ is convex. Thus, the denominator of (19) is positive. The numerator is also positive, which implies that $d\hat{x}/ds$ is greater than zero. Thus, increasing the minimally acceptable safety regulation has the effect of increasing the precaution taken.

The above result would imply that if $\tilde{x} < x^*$ (i.e., $\hat{x}(0) < x^*$) prior to the imposition of the _ex ante_ regulation, then the introduction of the regulation will promote efficiency. If, on the contrary, $\hat{x}(0) > x^*$, then the _ex ante_ regulation will exacerbate the inefficiency that exists with the negligence rule.

PROPOSITION 4. Imposition of an _ex ante_ regulation, given the existence of a negligence rule, will promote efficiency if the injurer would be under-protective regarding an accident without _ex ante_ regulation and will exacerbate inefficiency if the injurer would employ too high a level of precaution without _ex ante_ regulation.

This proposition may now be related to the conclusions of the previous section regarding the injurer's likely response to a negligence rule with uncertain enforcement of the legal standard. Recall that Propositions 1 through 3 established that injurers, when faced with only a negligence rule, may choose suboptimal precaution when

(1) uncertainty about the legal standard is sufficiently large;

(2) the marginal cost of precaution at x^* is large; or

(3) the distribution about the legal standard is sufficiently biased to the left of x^*.

It follows that when any of these conditions holds, injurers can be induced to increase their level of precaution by establishing a minimum safety regulation, s. Additionally, it follows from our discussion that because $d\hat{x}/ds$ is always positive, the imposition of an _ex ante_ minimum level of precaution in circumstances other than those noted above will cause injurers to take too much precaution.

Given that the introduction of an _ex ante_ safety regulation can reduce inefficiencies associated with the use of liability alone, the obvious next question is what level of the _ex ante_ regulation, s^*, will induce firms to choose $\hat{x}(s) = x^*$? From Proposition 4, we know that $s^* = 0$ if and only if $\hat{x}(0) \geq x^*$. Furthermore, if $\hat{x}(0) < x^*$, then $s^* > 0$ will promote efficiency. The question now is, what level of s will make $\hat{x} = x^*$? The answer can be found by substituting x^* for $\hat{x}$ in Eqn. 18 and solving for s^*. Stopping short of actually solving Eqn. 18 for s^*, we can rewrite it, using Eqn. 2, as

$$C'(x^*)[R(s^*) - R(x^*)] - A(x^*)q(x^*) = 0. \tag{20}$$

For this to hold, the bracketed term must be non-negative. This implies that the optimum level of the *ex ante* regulation is less than or equal to the optimal level of precaution, i.e., $s^* \leq x^*$.[14] Furthermore, generally $s^* < x^*$. Consider the implications of $s^* = x^*$. In this case $R(x^*) = R(s^*)$, which implies, using Eqn. (20), that the probability density at the social optimum ($q(x^*)$) must equal zero (because $A(x^*) > 0$). In other words, the only way s^* can equal x^* is if there is no chance that the legal standard will be at x^*. That is unlikely.

PROPOSITION 5. The optimum level of an *ex ante* safety regulation, s^*, given that a negligence rule exists, will be less than the socially optimal level of precaution, x^*, provided $q(x^*) > 0$. If $q(x^*) = 0$, then $s^* = x^*$ is optimal.

The implication of this result is that where optimal precaution calls for the joint use of *ex ante* regulation and a negligence rule, the optimal *ex ante* regulatory constraint should be set below the socially optimal level of care unless there is no uncertainty concerning the legal standard of care.

This result is illustrated in Figure 5 for two cases. Case I is the situation where negligence on its own over-provides precaution, x^+. An *ex ante* regulation cannot increase efficiency. In fact, for any $s > 0$ in case I, the level of precaution, $x_1(s)$, increases and deviates even further from the social optimum. Case II involves under-provision of precaution when the firm is subject only to liability regulation, $\bar{x}$. We see in both cases that as the ex ante regulation is raised, precaution increases. In Case II, the optimal ex ante regulation is where s* results in precaution of x*. Also shown in the figure is what we might call the "conventional wisdom" along the kinked line: liability alone induces optimal behavior for $s < x^*$; as soon as s reaches x*, then the ex ante regulation becomes binding and precaution is provided at level s.

V. CONCLUSIONS

The propositions presented above have profound implications with regard to the conditions where ex ante regulation alone or both ex ante regulations and ex post liability rules should be used jointly in a wide range of public policies for dealing with external costs. We introduced uncertainty into a defendant's assessment of the legal standard of care and deduced the consequences of this uncertainty on the defendant's choice of precaution under a negligence rule.

Propositions 1 through 3 indicate the effect of uncertainty about the legal standard of care and the injurer's marginal cost of precaution on under- or overprecaution. We next demonstrated that the introduction of an ex ante constraint specifying a minimally acceptable level of precaution (a safety regulation) will always cause the injurer to increase precautionary levels. We concluded that the joint use of ex ante and ex post regulation will enhance efficiency under the following conditions: if there is great uncertainty in the determination of the legal standard of care; or if the distribution is highly biased to the left of the socially optimal level of care; if the injurer's marginal cost of precaution is large at the social optimum. Otherwise, ex ante and ex post regulation should be used separately.

We used our model to show the relationship between the optimal ex ante constraint and the socially optimal level of care. Proposition 5 clearly indicates that if it is efficient to use both policies, then the level of the ex ante regulation should not be set at the social optimum but rather at a lower level. That proposition might further be taken to indicate that ex ante regulations should be used alone when the probability of a successful suit against the injurer is zero. This might be the case when there is a great deal of uncertainty associated with a harm, as might occur when the harm is so new that those it affects and the consequences of the harm are unclear but suspected of being catastrophic, or when the level of accident costs borne out by the injured party is so small that he or she might not even recognize it, even though many individuals are affected.

Further implications for the optimal mix of regulatory policies arise from a comparison of the assumptions of Propositions 1 through 4 with actual circumstances. This comparison may reveal both positive and normative insights. For example, it might be possible, using the model discussed here, to explain why new harms--e.g., the escape of toxins into the environment--are typically regulated through ex ante command and control policies, while harms arising from more familiar sources--e.g., automobiles--are typically regulated by exposing the injurer to ex post liability.

There are several refinements to the model that seem appropriate. First, our model includes only the injurer's costs of avoiding the harm. A complete analysis would include an explicit treatment of the victim's precautionary behavior under uncertainty. Second, a comparison of the administrative costs of the tort liability system and of the _ex ante_ system should be made. Third, uncertainty surrounding the legal standard could be further broken down into its different components--e.g., evidentiary uncertainty, uncertainty regarding the technology of precaution, uncertainty regarding the level of accident costs, and uncertainty about the victim's willingness to bring a tort action--in order to allow the examination of the conditions under which alternative _ex post_ liability rules or a different mix of _ex ante_ and _ex post_ regulation might be efficient. Fourth, the possibility of bankruptcy could be introduced. Finally uncertainty regarding the _ex ante_ regulation could be introduced into the model. We have assumed that there is no error in the determination or enforcement of the _ex ante_ standard. To the extent that such uncertainty exists, then the case for complementary use of _ex ante_ and _ex post_ regulation becomes more complex. While it is clear that such uncertainty would not affect our prohibition of the use of _ex ante_ regulation when injurers tend to oversupply precaution due to uncertainty regarding the enforcement of the _ex post_ liability rule, it should affect the level of regulation when injurers undersupply precaution. It could be argued that if regulators have enough information to set a lower bound on precaution _ex ante_, then the liability system should also have enough information to set the same lower bounds. But this reform cannot be affected within the tort liability system as it presently exists. It can only be achieved by supplementing exposure to tort liability with exposure to _ex ante_ regulation.

FOOTNOTES

[1]Brown (1973) and Diamond (1974) were among the first to mathematically articulate Calabresi's (1970) theories of liability as a means of controlling externalities.

[2]An exception is the recent work of Shavell (1984a, b) which is discussed in more detail later in this paper.

[3]The classic comparison of the efficiency aspects of these alternate methods of minimizing this type of externality is given by Ellikson (1973).

[4]Many authors (e.g., Diamond, 1974; Brown, 1973; Cooter et al, 1979) explicitly consider the level of precaution taken by the potential injured party. While this is realistic and leads to richer conclusions in many analyses, it is tangential to the purposes of this paper which is why we assume the potential injured party acts optimally.

[5]We avoid the complications of contributory negligence by assuming that potential victims are taking the socially optimal amount of precaution.

[6]Diamond (1974) views this uncertainty from a somewhat different perspective. He assumes the firm knows the legal standard of care with certainty but the firm is uncertain about how its precautionary measures translate into safety levels and it is these safety levels that are measured by the court. However, the effect is the same: for a given level of precaution the firm is uncertain as to whether he is above or below the legal standard. Cooter and Ulen (1986) examine evidentiary uncertainty, or uncertainty in exactly how a court will interpret evidence in deciding whether the firm's level of precaution was above or below the "legal standard."

[7]Craswell and Calfee (1986) do prove that for a legal standard symmetrically distributed about x^*, small levels of uncertainty lead to over-supply of precaution, provided density is concentrated at x^* for low levels of uncertainty.

[8]Alternatively, one could argue that the support should be $[0,\infty]$.

[9]The negative sign in front of the term $[A(\tilde{x})q(\tilde{x})]$ is due to the fact that $R'(\tilde{x}) = -q(\tilde{x})$.

[10]Let X and Y be two random variables with cumulative distribution functions G and F, respectively. Second-order stochastic dominance states that X is more uncertain than Y if

$$\int_{-\infty}^{t} [G(s) - F(s)]ds \geq 0 \quad \text{for all } t.$$

This includes the case of a mean-preserving spread (Lippman and McCall, 1981).

[11]This result for overprotection was proved, for the special case of symmetric distributions, by Craswell and Calfee (1986).

[12]An alternative explanation of this result can be made with reference to Equation 9 and Figure 3. The last two terms of Equation 9, the marginal liability costs, are the savings from increased precaution. Equation 9 can be rewritten as

$$C'(\tilde{x}) = -A'(\tilde{x})R(\tilde{x}) + A(\tilde{x})q(\tilde{x})$$

An increase (decrease) in the injurer's uncertainty at a point $\tilde{x}$, as shown in Figure 3, decreases (increases) the right-hand-side of this equation. This comes about because both $R(\tilde{x})$ and $q(\tilde{x})$ become smaller (larger) as uncertainty increases (decreases). At the equilibrium this implies that a lower (higher) level of precaution is taken by the injurer.

[13]This is a generalization and extension of the case considered by Craswell and Calfee (1986) of the whole distribution shifting to the right or left, although our results support their conjectures.

[14]In (20), the term $C'(x^*)$ is positive as is the term $A(x^*)$, given our earlier definitions of these functions. In order for Equation 20 to equal zero, $R(s^*)$ (the probability that s^* is less than the ex post standard) must be greater than that same probability at x^*. This relationship between $R(s^*)$ and $R(x^*)$ can only be true if $s^* < x^*$.

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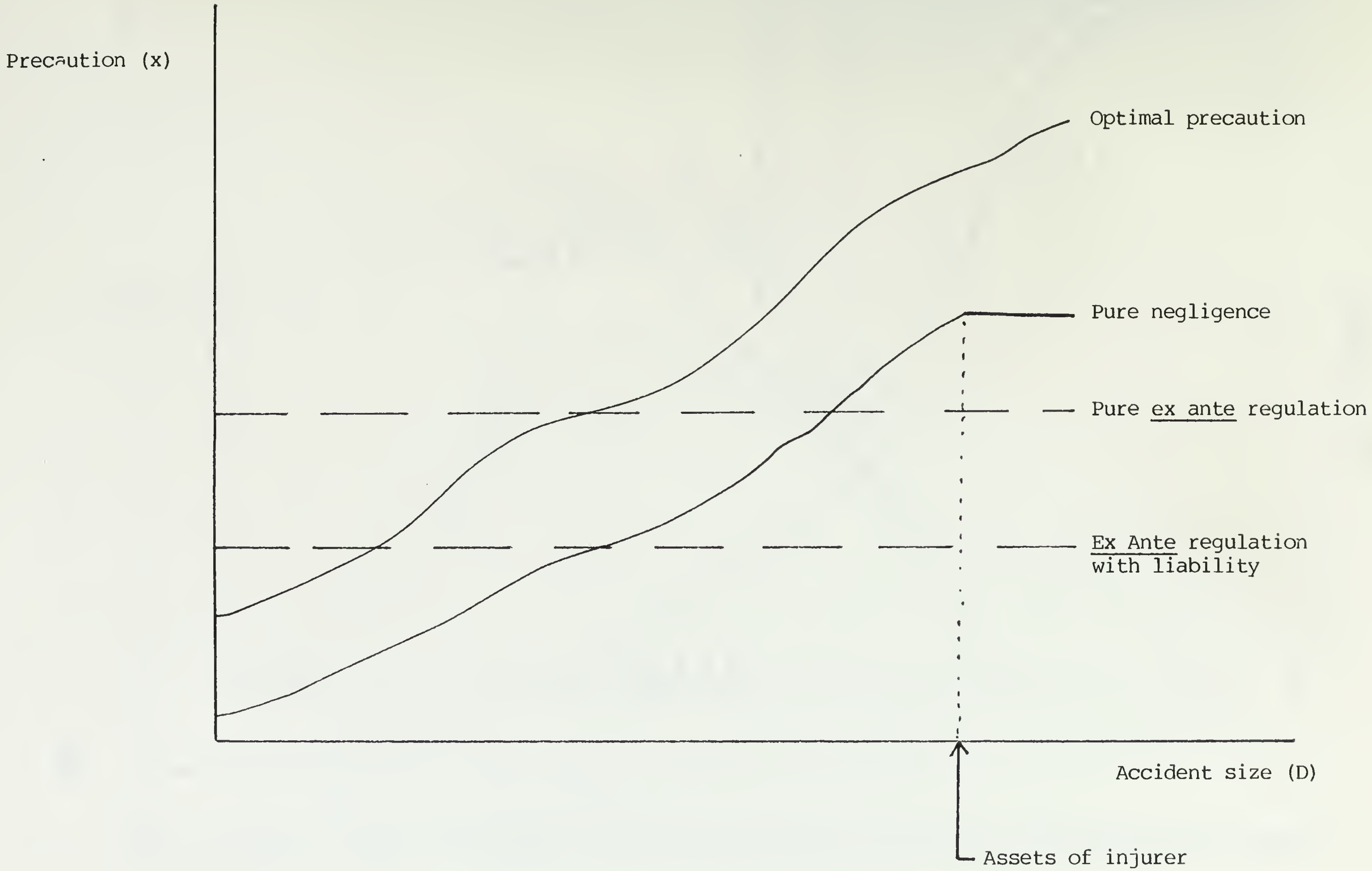
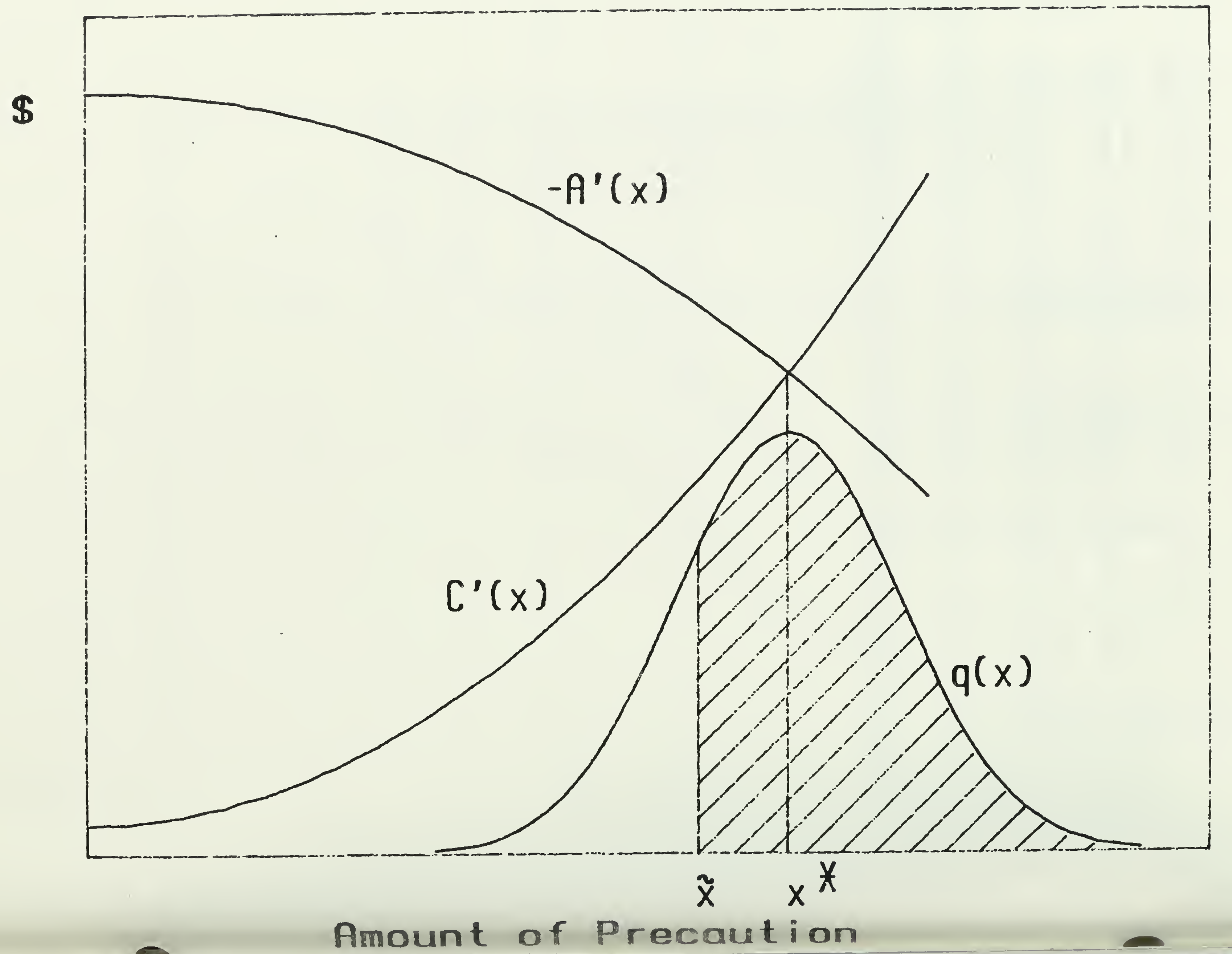


Figure 1: _Ex Ante_ and _Ex Post_ Regulations with Bankruptcy and _Uncertainty of Suit_

Figure 1.

The Social Problem with Evidentuary Uncertainty for the Injurer



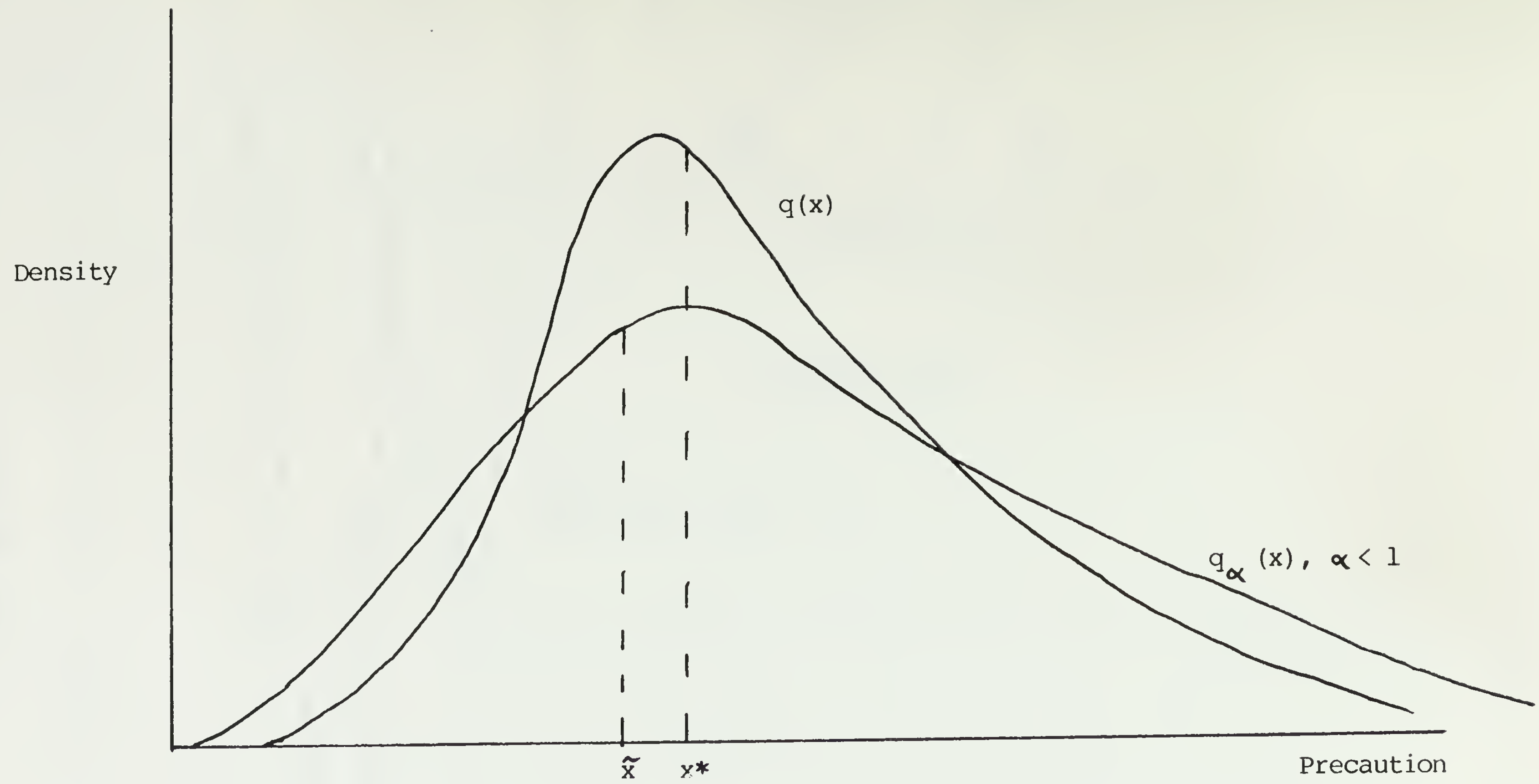
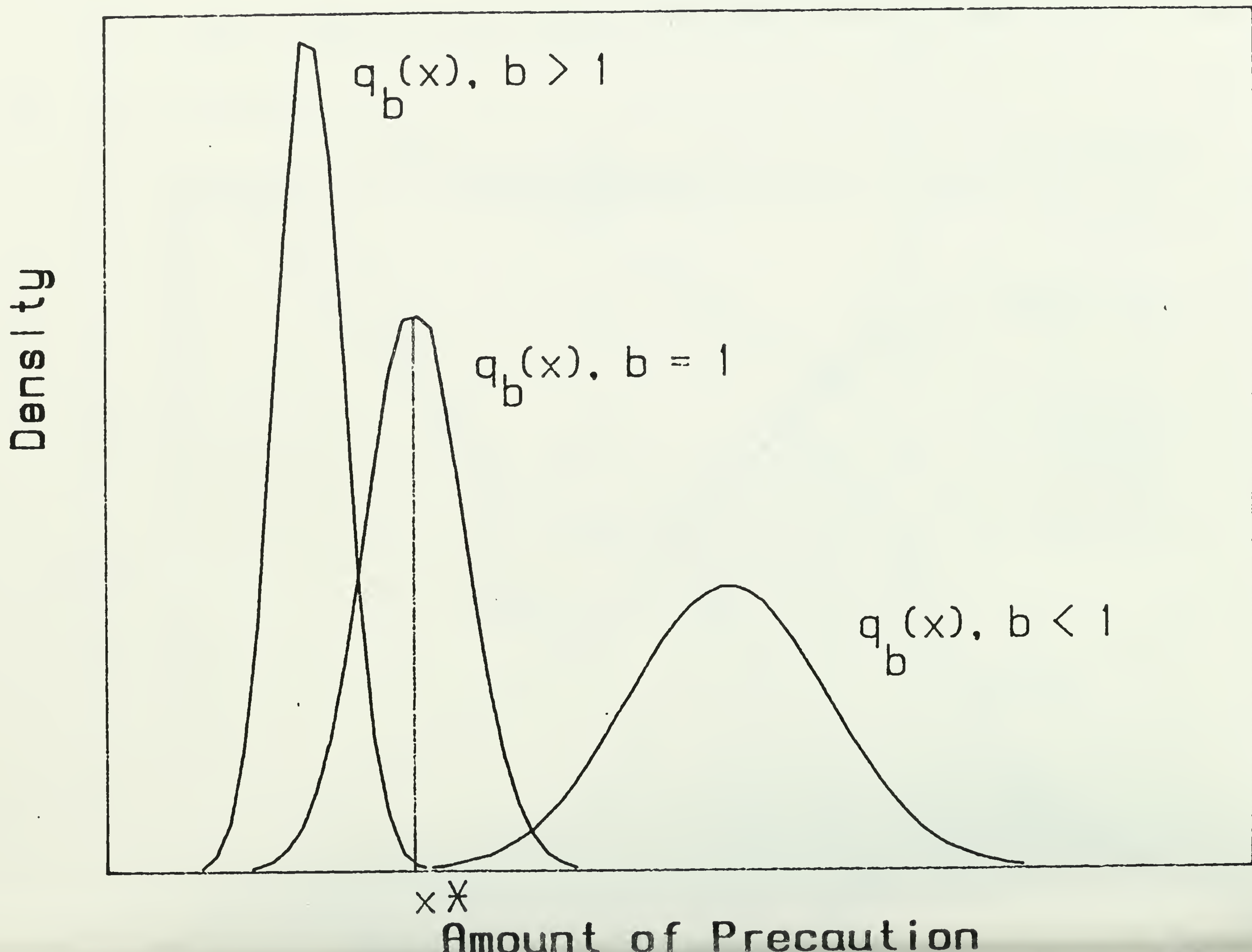


Fig. 3: A mean-preserving increase in uncertainty can lead to under-provision of precaution.

Figure 4.
Biased Uncertainty



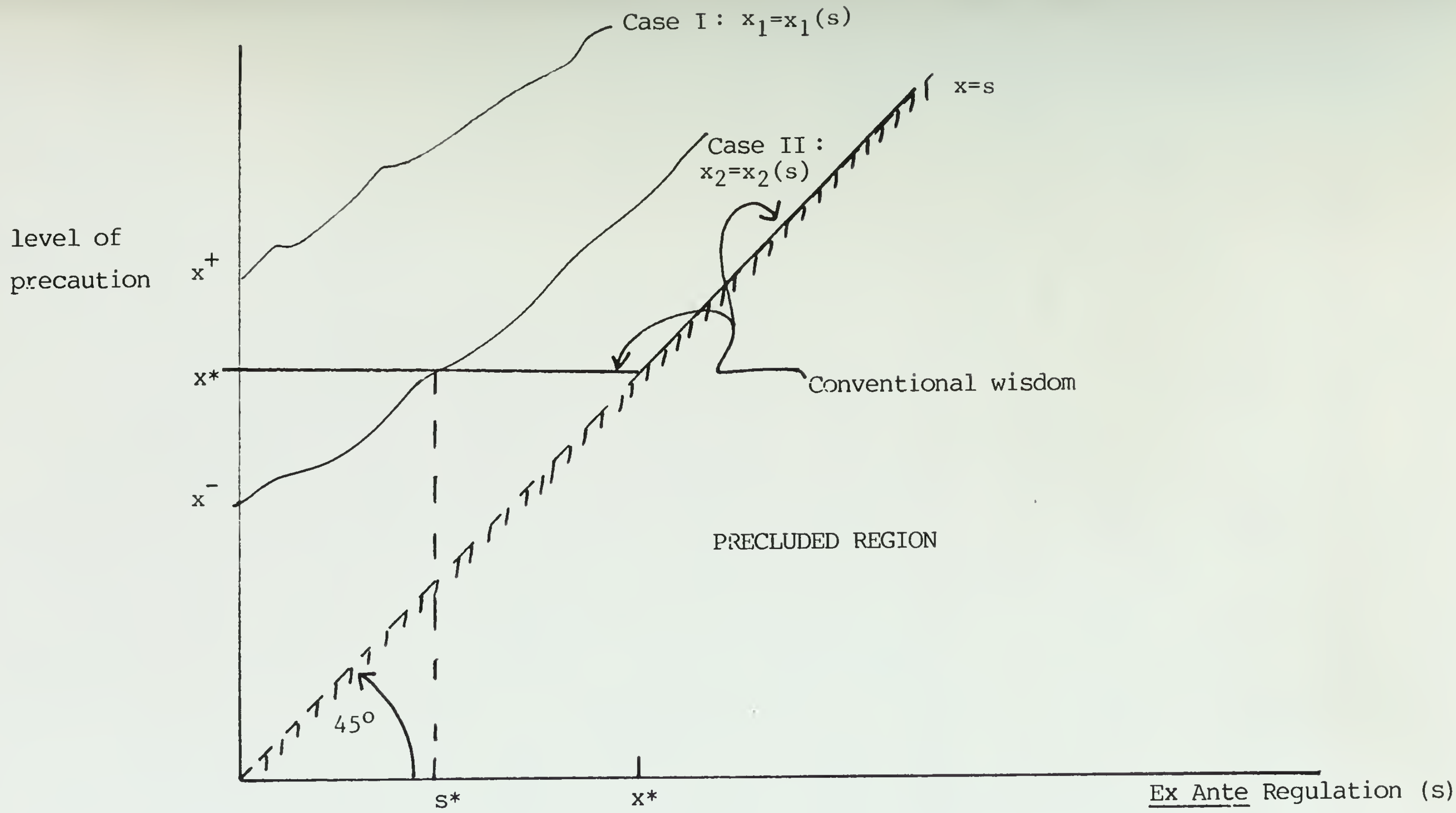


Figure 5: The effect of Ex Ante regulation with ex post liability

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